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Low-Speed-Flight Research Program

FLIGHT MEASUREMENTS OF AUTOMATIC TRAILING EDGE SUCTION ON A SAILPLANE

By

AUGUST RASPET

Conducted Under

CONTRACT Nonr 223(00)

By

THE ENGINEERING RESEARCH STATION

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Research Report No. 3 Sept. 30, 1952

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FLIGHT MEASUREMENTS OF AUTOMATIC TRAILING EDGE SUCTION ON A SAILPLANE

By August Raspet

Summary

This paper concerns an investigation made on a sailplane equipped with a trailing edge suction slot which covers two-thirds of the wing span. Special wing tips based on Hoerner's work (Ref. 1) were installed and explored for pressure distribution. An experimental iteration method was used to arrive at a location and shape for the opening on the tips' upper surface which would yield a high suction pressure. The flow coefficient obtained was of an order that should have resulted in aerodynamic improvements similar to those measured on a section of the same airfoil and discussed in a previous work by this author (Ref. 2).

The results obtained in these tests, however, hold no promise for application to airplanes in general. No improvement in the lift/drag ratio was found, nor was there any essential improvement in over-all drag. The maximum lift coefficient was not increased beyond that obtainable on a plain wing. Rolling response measurements of a fully asymmetrical distribution of suction through the trailing edge slot yielded a roll rate about 10% of that developed by the ailerons.

Introduction

In two papers (Ref. 3,4) Regenscheit described a wind tunnel research into the properties of trailing edge suction. In reference 4 he took up the possibilities of obtaining self-induced suction by utilizing the wing-tip vortex. Lippisch (Ref. 5) later suggested the top of a square wing tip as being a desirable location for the suction opening. In the work described in this paper, Hoerner's concept of a tip intended to push the tip vortex outward from the tip was constructed. The upper surface of this tip yielded an area which proved to be a good source of suction.

ARRANGEMENT OF EXPERIMENTAL SAILPLANE

A standard TG-3A war surplus sailplane was used in these tests. The wing was completely rebuilt in order to provide a precise outside contour, an interior offering low internal pressure losses to the flow, and tips capable of furnishing large suction pressures.

Figures 1 and 2 show a view of the experimental wing. Additional ribs and small riblets were added behind the spars in order to prevent the fabric's deflection under suction pressures. The leading edge of the wing up to 34% of the chord was controlled to a waviness of less than $\pm$ 0.004, which was measured with a surface gauge of the spherometer type having fixed outside control points spaced at 2.4 inches, i. e. 4% of the chord.

In addition, the truss ribs had all of their corners rounded and the plywood gussets filled with putty. This was done to reduce the pressure losses to the internal flow.

The trailing edge was so constructed that various inserts could be placed in the slot. This permitted the slot position to be moved over a small region of the chord. The slot inserts were designed as diffusers in order to recover some of the pressure energy of the flow (see Fig. 3). Even with relatively small flows through the slot, one would find high velocities in the tip section. For this reason, the wing near the tip was constructed as a double-skinned surface and thereby had a completely hollow interior except for a small steel strut supporting the aileron. The tip itself was made hollow in order to permit air flow through its interior.

At the root of the wing an opening was provided through which air could flow from the fuselage to the wing tip through the wing's interior. This permitted measurements of flow rates to be made through the tip with a calibrating venturi installed in the root opening.

In order to have a larger cross-section at the tip, about 18 inches were cut off the tip end of the wing and a new tip design (shown in Fig. 4) was installed.

The aileron was thereby reduced to 5.5% of the wing area.

INVESTIGATION OF TIP AS SUCTION SOURCE

A simple pressure distribution of the top surface of the wing tip was first made (Fig. 5). In this illustration the pressures are shown as ratios of the dynamic pressure. Since the flow out through this surface would alter the pressure distributions, it was felt best to approach the optimum slot shape by a series of successive cuts rather than by cutting an opening in the tip surface which followed an isobar of the value corresponding to the desired suction pressure. For this reason a small opening following the isobar, -1.8, at high lift coefficient, was cut in the surface and a second pressure distribution was surveyed (Fig. 6). This operation was performed until the shape of the opening approximately followed the isobar, -1.0q. This opening yielded a flow coefficient of 0.002 at $C_L = 1.4$ through the No. 1 slot (see Figs. 7, 8, and 9).

By means of a calibrated venturi flow meter built into the wing tip itself, a series of measurements of flow coefficient as a function of lift coefficient of the sailplane was made for each of the slot shapes. Measurements for the slot extending over 17.8 feet of each wing are shown in Figure 10.

DRAG POLAR DETERMINATION

The drag polar of an airplane is an excellent criterion of the performance of the airplane. On a sailplane, where no engine effects need be considered, the drag polar is the sole criterion. If trailing edge suction is to offer economic advantages in air commerce, it must show an improvement in the drag polar over that of the clean wing. Such a polar comparison is shown in Figure 11. These polars were obtained by averaging six independent flight tests of each configuration. The flight tests were made at early dawn in still air by measuring the sinking speed of the sailplane at various forward speeds.

It is evident from these results that the drag polar is very slightly improved by automatic trailing edge suction at lift coefficients 0.9 to 1.2. At low lift coefficients corresponding to cruising flight the wing with trailing edge suction has a higher drag than a normal wing. This is also true at lift coefficients above 1.2.

A similar measurement was made on the sailplane with a 2 inch wide slot extending nearly to the trailing edge (Fig. 12). In this case the drag polar for the plain wing shows a lower drag for the entire flight range of the sailplane. This would indicate that at a higher flow coefficient the drag tends to increase. Such a conclusion is supported by results obtained in earlier suction tests (Fig. 4 of Ref. 2). The fact that the drag polar is not improved as much at high lift coefficients as was expected from these section tests led to an investigation by a drag polar determination of the sailplane with air flowing out of the tip openings but with trailing edge slots closed. The air required for the flow was obtained at an inlet on the nose of the fuselage. Figure 13 shows that the aerodynamic effect of the flow through the opening used as an automatic suction source is to increase the drag at low lift coefficients. At moderate to maximum lift coefficients there is no effect on the lift-drag polar. From this measurement it may be inferred either that the losses inside the wing are of a magnitude equal to any gains in drag, or that the lift increment due to trailing edge suction was nullified by an adverse effect on the lift by the flow through the tip. The rolling response measurements to be described later bear out the latter conclusion.

ROLLING RESPONSE MEASUREMENTS USING FULL ASYMMETRIC TRAILING EDGE SUCTION

One of the rather intriguing ideas presented by Regenscheit was that of using automatic trailing edge suction as a lateral control (Ref. 6) and thus eliminating the movable flap. With such a control aileron flutter would not be a consideration in airplane design. The use of an autopilot would be simplified because the servo would need to include only a flow control valve or a small tongue valve in the trailing edge of the wing permitting flow through a slot either on top or bottom surface of trailing edge.

The technique in the evaluation of automatic trailing edge suction as a lateral control consisted simply of closing the slot on one side of the wing while allowing the other to operate through automatic suction from the opening in the upper surface of the wing tip. In flight the rolling tendency of the asymmetrical automatic trailing edge suction was counteracted with a deflection of the normal ailerons, maintaining the skid at zero by means of a tuft indicator on the nose of the fuselage. The geometry of the wing used is as follows:

Wing span	52.0 feet
Wing area total	233.3 square feet
Aspect ratio	11.5
Intercepted fuselage area	10.4 square feet
Aileron area, both	13.04 square feet
Aileron chord	1.26 feet
Root chord of wing	5.00 feet
Tip chord of wing	3.21 feet
Taper ratio (weighted)	0.824
Aileron area/wing area	0.056

Flight tests of the automatic trailing edge suction lateral control showed, in general, very weak rolling moments. This behavior is in agreement with maximum lift determinations made by measuring the stalling speed with various trailing edge slot designs. Only near the stall speed was sufficient rolling effect observed to be definitely measurable. With the full length slot (17.8') the maximum rolling responses were determined as follows:

Slot	Aileron deflection	$\frac{pb}{2V}$
No. 1	1.9°	0.0088
No. 3	1.4	0.0066

Slot	Aileron deflection	$\frac{pb}{2V}$
No. 4	0.95	0.0044
No. 5	0.47	0.0022

Since the values of helix angle $\frac{pb}{2V}$ are very small, of the order of 0.1 of the values for desireable lateral control, an effort was made to improve this control by concentrating the suction toward the outboard section of the slot just inboard of the small aileron. The effect was an increase both in the suction flow coefficient and in the moment arm for the applied lift force generated by the suction. The flow coefficient obtained from measurements in flight with the outboard 66 inches of the slot opened is shown in Figure 14. It can be seen from this figure that at high lift coefficients a flow coefficient of 0.007 is obtained. If the slope of lift versus flow coefficient (amplification) were as high as is shown by Regenscheit (Reg. 3, 4) i. e. 100, a section lift increment of 0.7 would have resulted. This C_l would require a countering total aileron deflection of 13.0°. It is clearly evident from the following table that no such effectiveness was observed:

Maximum Rolling Response - Outboard 66" of Slot Open

Slot	Aileron deflection	$\frac{pb}{2V}$
No. 1	0.95°	0.0044
No. 3	1.90	0.0088
No. 4	1.43	0.0066
No. 5	0.95	0.0044

In general, though the concentration of slot outboard resulted in an essential increase in helix angle, the results obtained would still not indicate sufficient control for safe flight operations.

From these results one must conclude that, with present configurations of slot and tip opening, a lateral control system utilizing automatic trailing edge suction would be totally unsuitable because it lacks sufficient effectiveness for lateral control, even in still air.

MAXIMUM LIFT COEFFICIENT

Since the suction induced by the wing tip vortex increases with the lift coefficient, one would expect, if trailing edge suction controls the turbulent separation, a relatively large increment in maximum lift coefficient. This can readily be measured by the decrease in minimum speed. Figures 11 and 12 give the maximum lift coefficients so measured:

Clean ship - no slot	max C_L = 1.43
No. 1 slot open full length	max C_L = 1.37
No. 2 slot open full length	max C_L = 1.36.

It is evident from these values that there is a small loss of maximum lift coefficient with trailing edge suction and a wing tip source. The exact behavior of the slot action must yet be determined in its full open span length with an independent source of suction such as an electric blower. This would permit the lift increment to be determined over a range of flow coefficients, thereby separating the effect of the tip suction sources on lift from those of the trailing edge slot, and would yield measurements similar to those made on a section (Ref. 2), except that the slot would cover at least two-thirds of the span.

IMPROVEMENT OF TIP SUCTION SOURCE

In an effort to improve the suction flow through the tip opening, a deflector one inch high was installed in the inboard edge of the tip opening. No effort was made to duct the flow internally through the tip. A comparison of the flow through the original opening and the same with the deflector is shown in Figure 15. Approximately 30% more flow is gained at low lift coefficients. It was felt, however, that the drag of the additional deflector would not be compensated by any over-all decrease in drag due to the trailing edge suction. If an efficient trailing edge suction configuration is eventually developed, the deflector might fulfill a useful function.

Conclusions

A suction source capable of yielding a maximum suction of 2q with no flow at a lift coefficient of 1.4 was found by an iteration process on the upper surface of a Hoerner tip. This suction source yielded a flow coefficient of 0.0023 with a trailing edge slot covering 65% of the span of the sailplane used in this research. A slight improvement in suction was effected by using a deflector on the inboard edge of the suction opening. With this tip suction source connected by a low-loss ducting, through the interior of the wing, to a trailing edge suction slot, it was found that

1. From a drag polar determination a loss of performance would result with automatic trailing edge suction.

2. The maximum lift coefficient is slightly lower when automatic trailing edge suction is in operation than it is on a plain wing.

3. By applying trailing edge suction asymmetrically, a rolling behavior totally insufficient for effective lateral control was measured.

In general, the results obtained by full scale flight tests of trailing edge suction indicate that more work needs to be done on the possibility of combining distributed suction with trailing edge suction. This type of flow control would more nearly fit requirements of the theoretical studies in which potential flow is assumed. Some promising preliminary results have been obtained with such a configuration.

In these tests perforated suction was applied from the 35% chord point to the slot at 97% chord. When suction was applied at flight near maximum lift coefficient, a relatively strong rolling moment was found with a test section 45 inches wide and only 18% of the semi-span from the fuselage center line. This section was installed on one wing only. The study is being continued in order to evaluate distributed suction plus trailing edge suction as a drag reducing and lift augmenting aerodynamic device.

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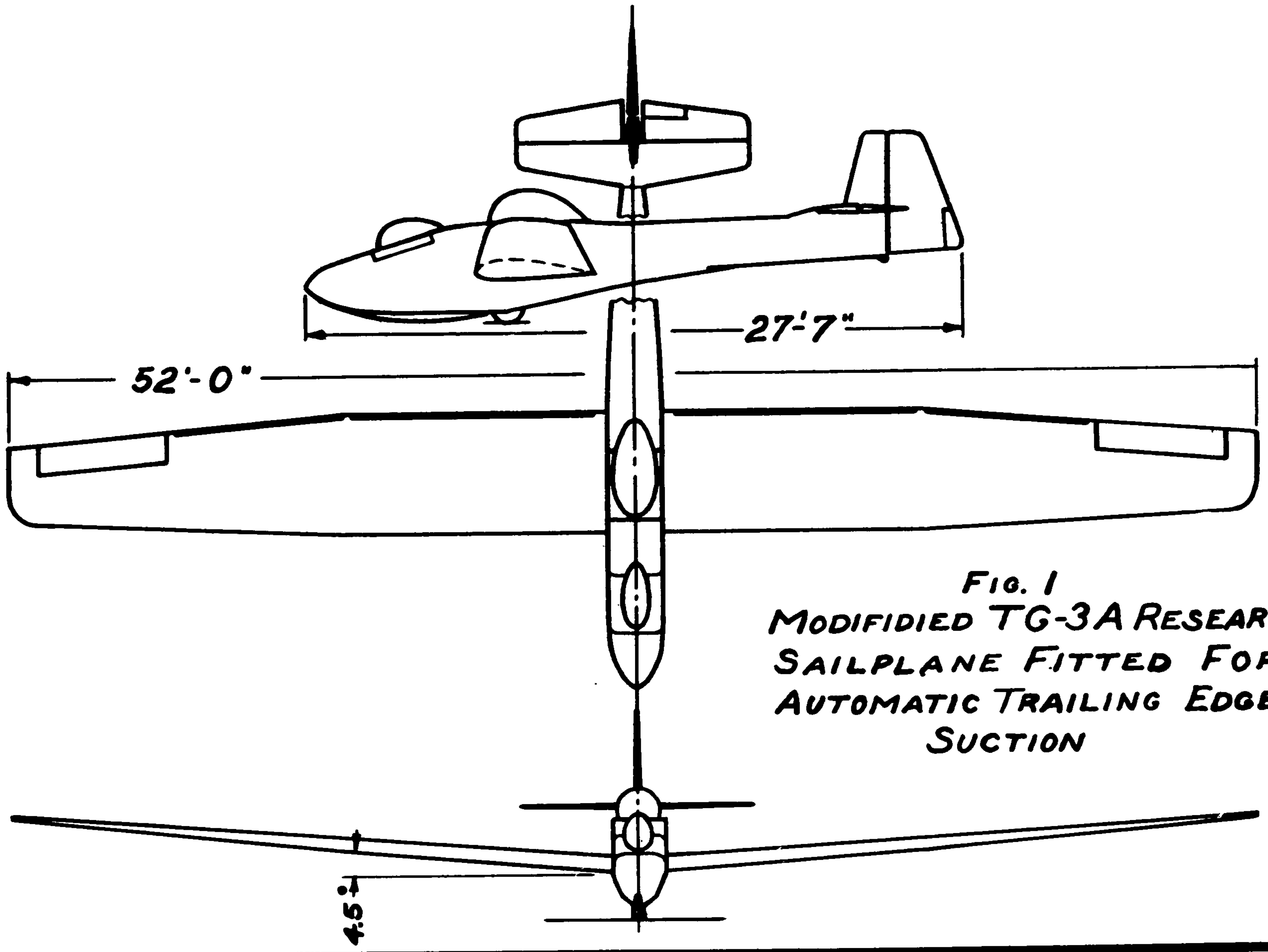


Fig. 1
Modifidied TG-3A Research Sailplane Fitted For Automatic Trailing Edge Suction

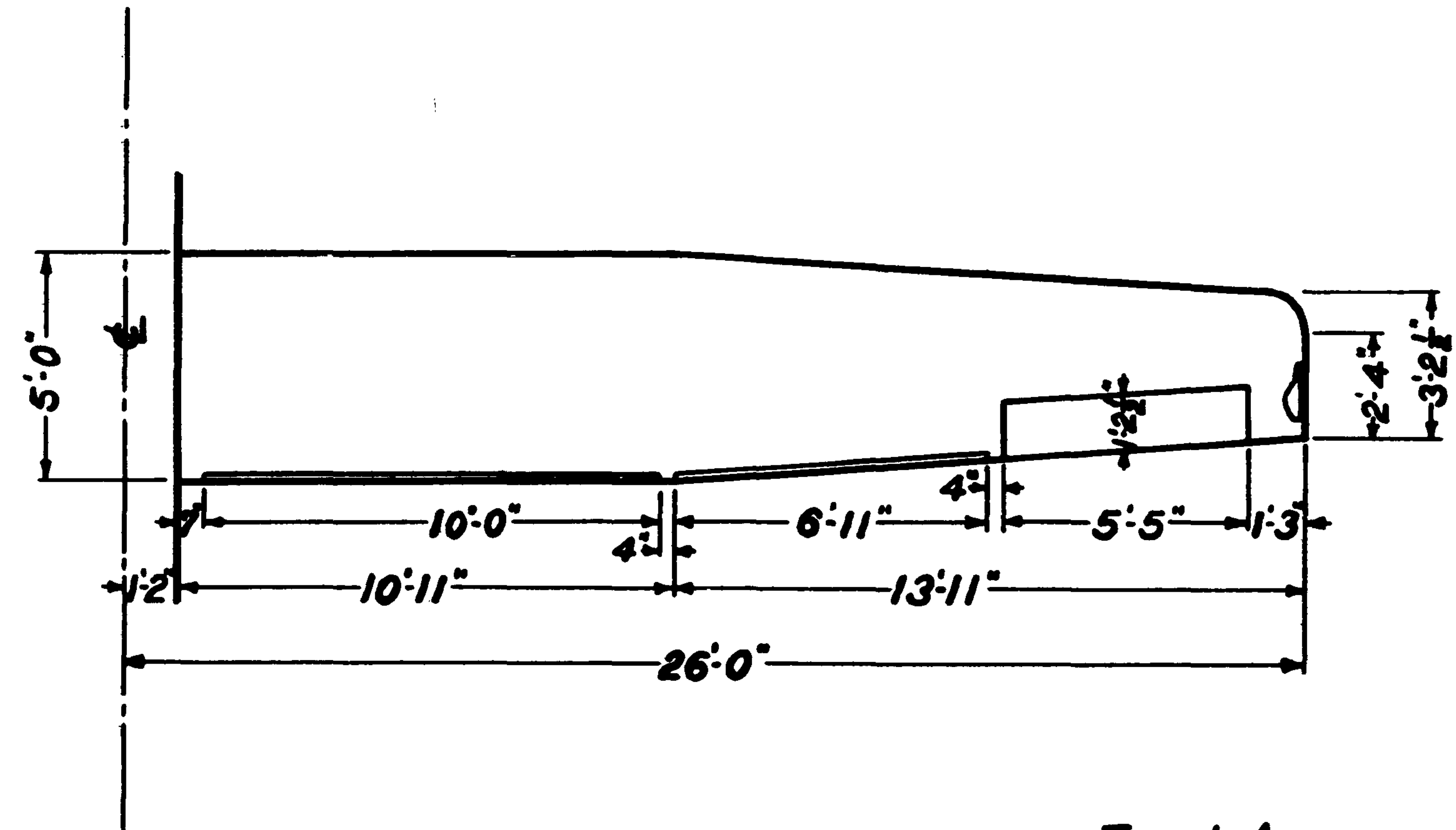


Fig. 1-A
Wing Panel Of TG-3A
Modified For Automatic
Trailing Edge Suction

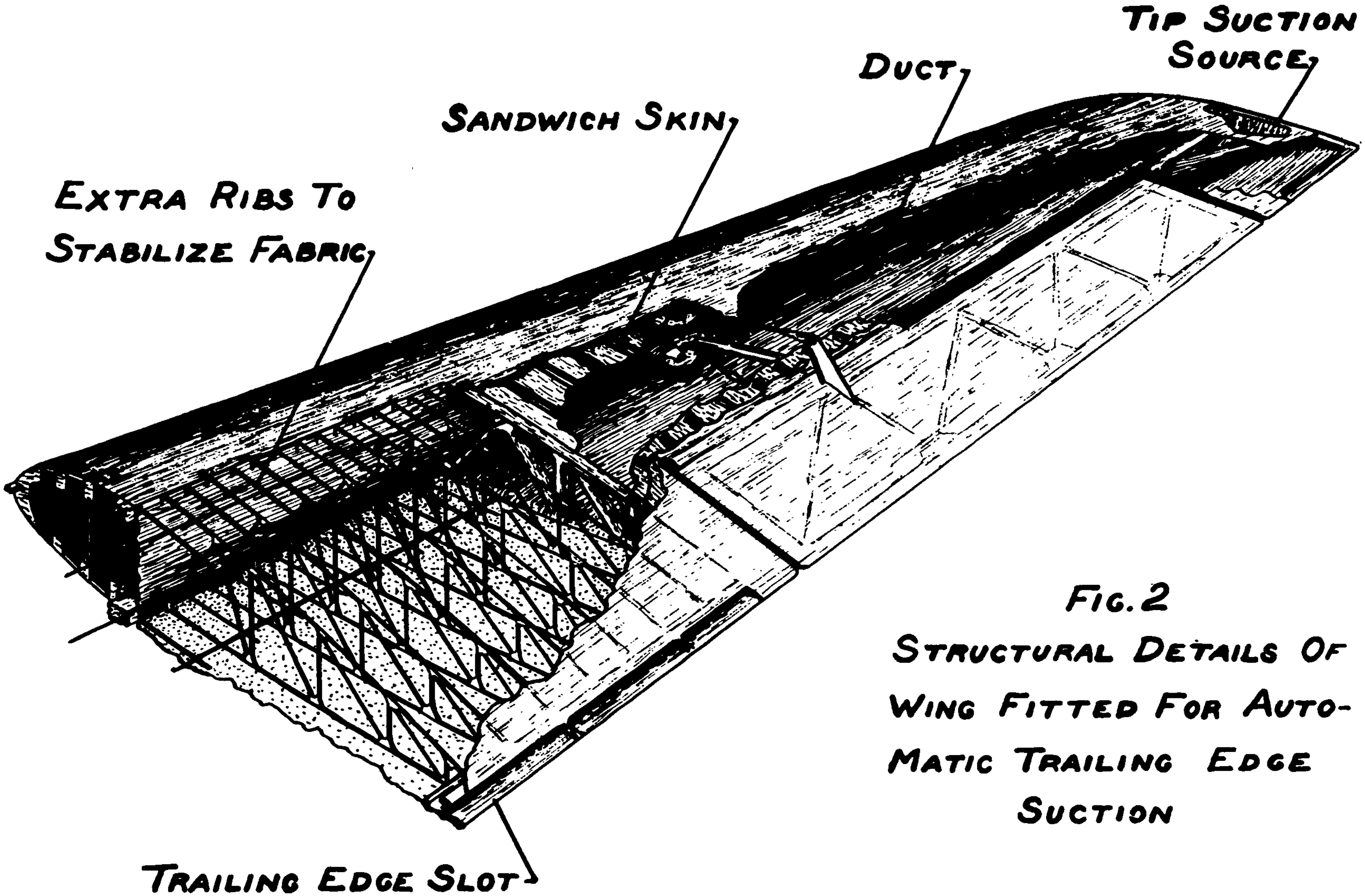


Fig. 2
Structural Details Of Wing Fitted For Automatic Trailing Edge Suction

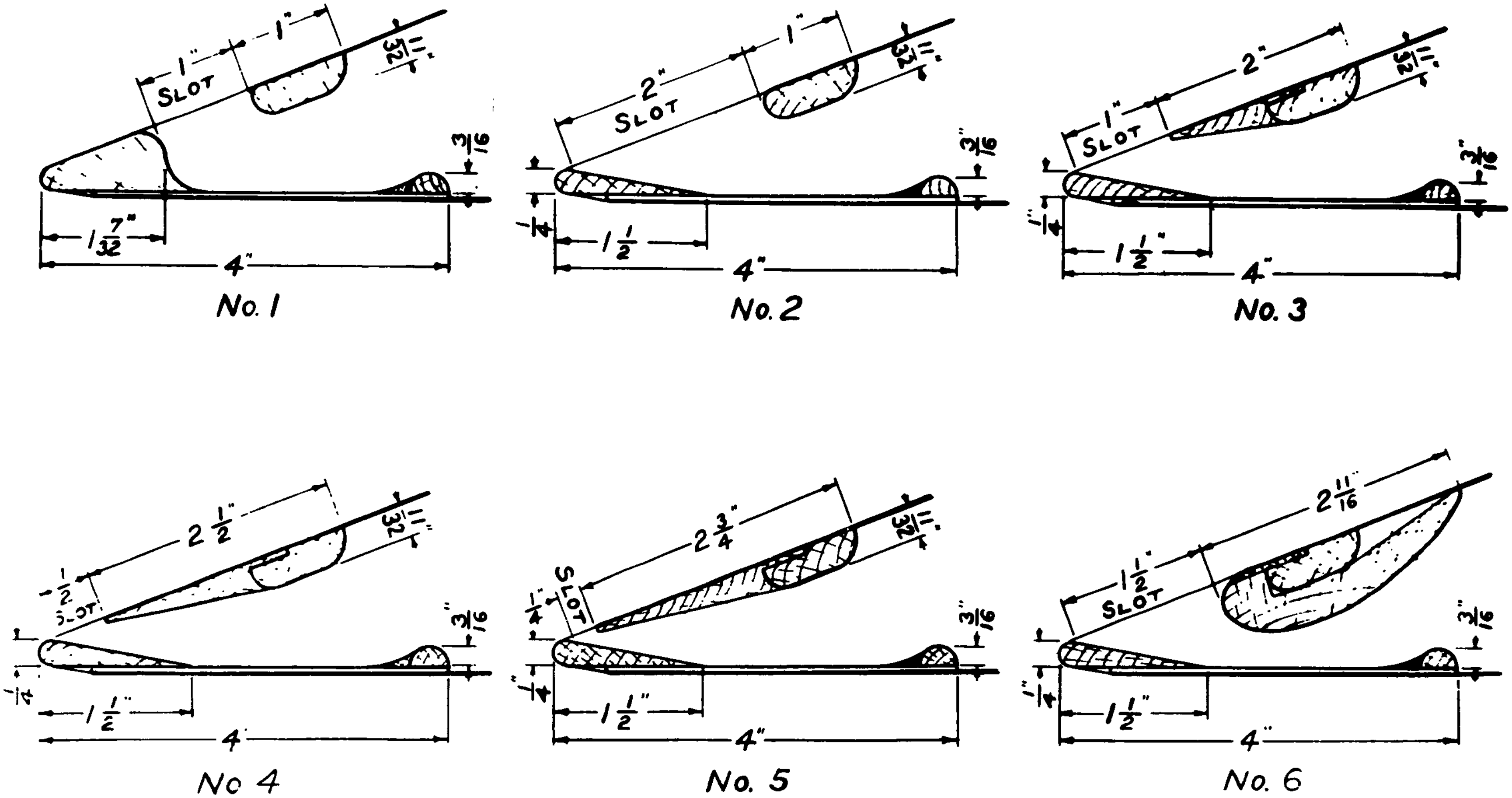


FIG. 3

SHAPES OF SIX TRAILING EDGE SUCTION SLOTS TESTED ON NACA 4416 AIRFOIL - 49" TO 60" CHORD

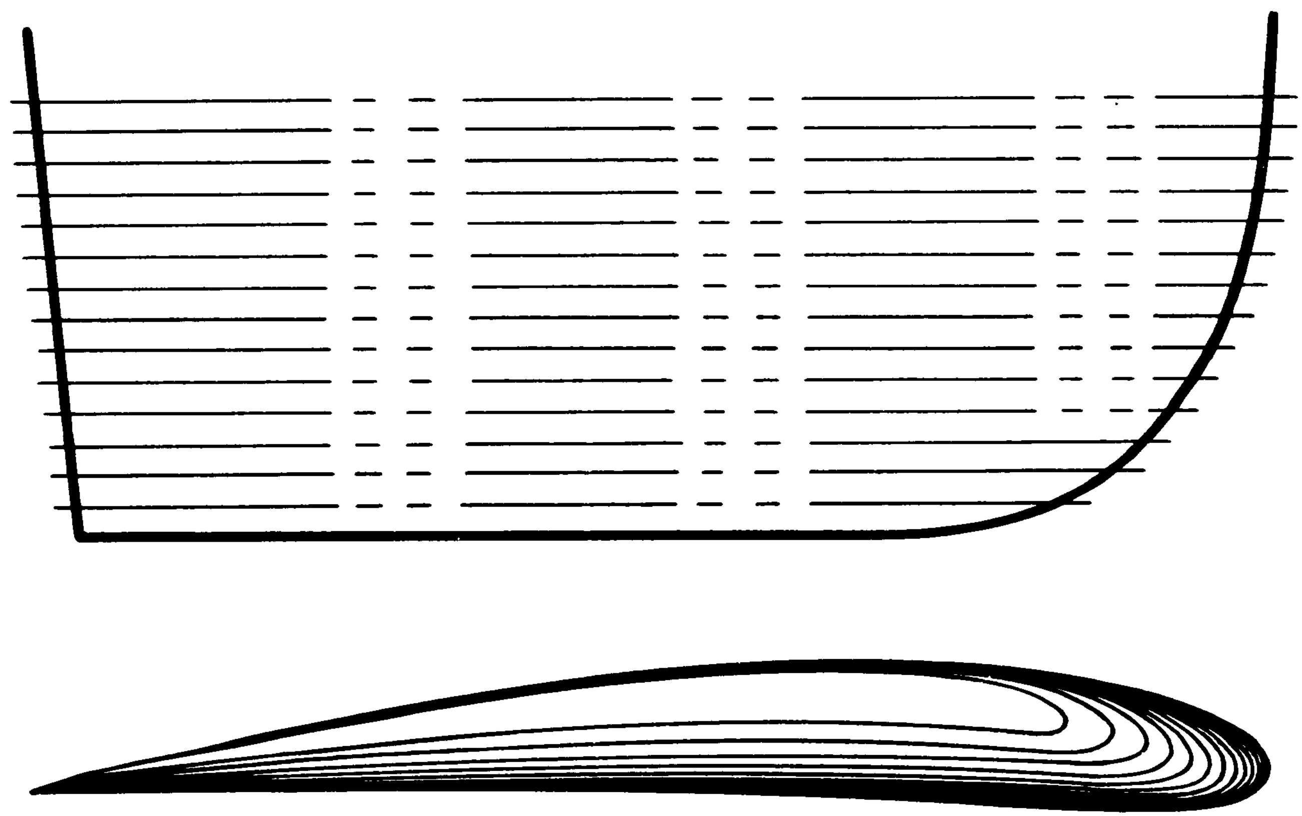


Fig. 4
Shape Of Hoerner Tip Used
As Suction Source For Automatic
Trailing Edge Suction

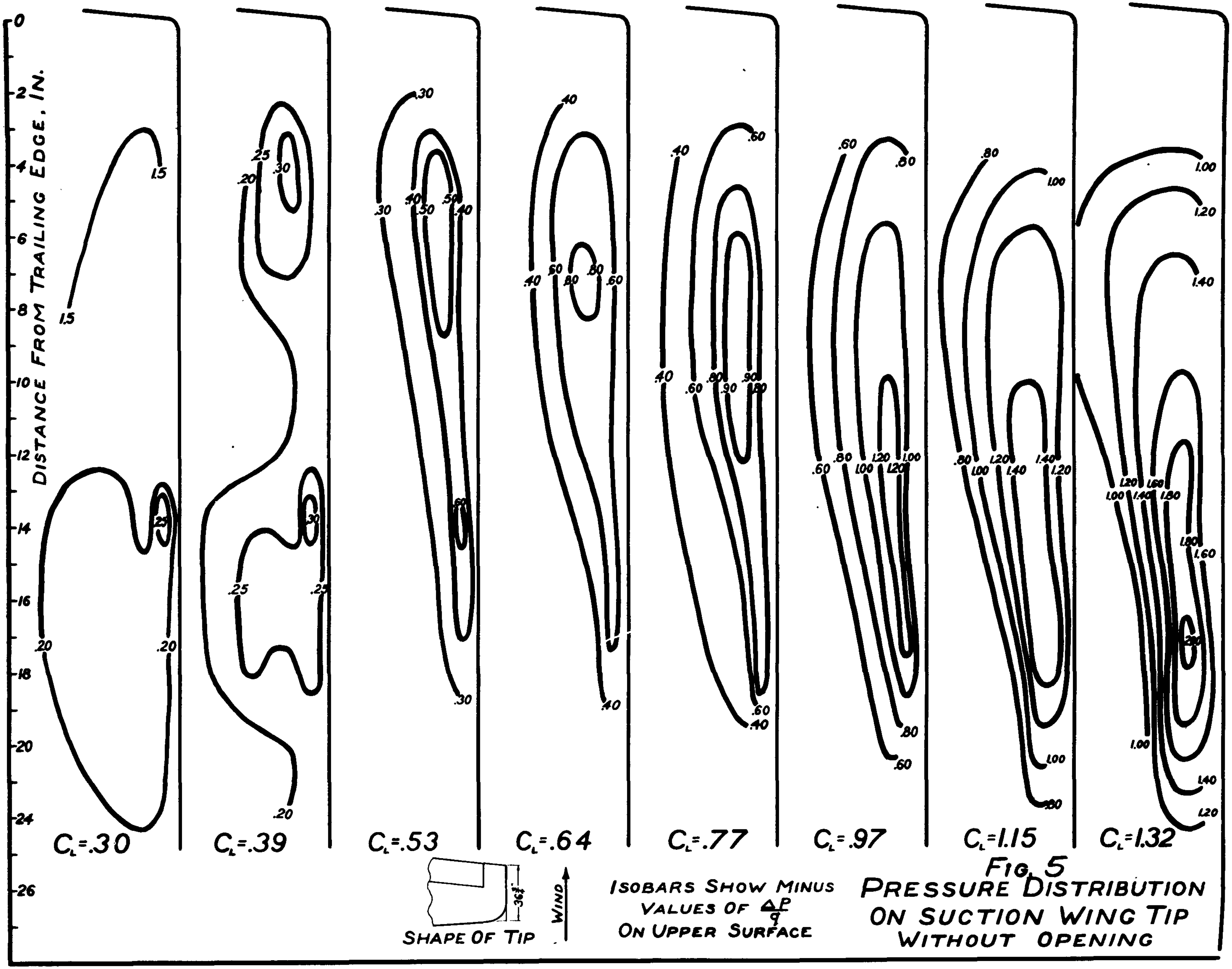


FIG. 5
PRESSURE DISTRIBUTION ON SUCTION WING TIP WITHOUT OPENING

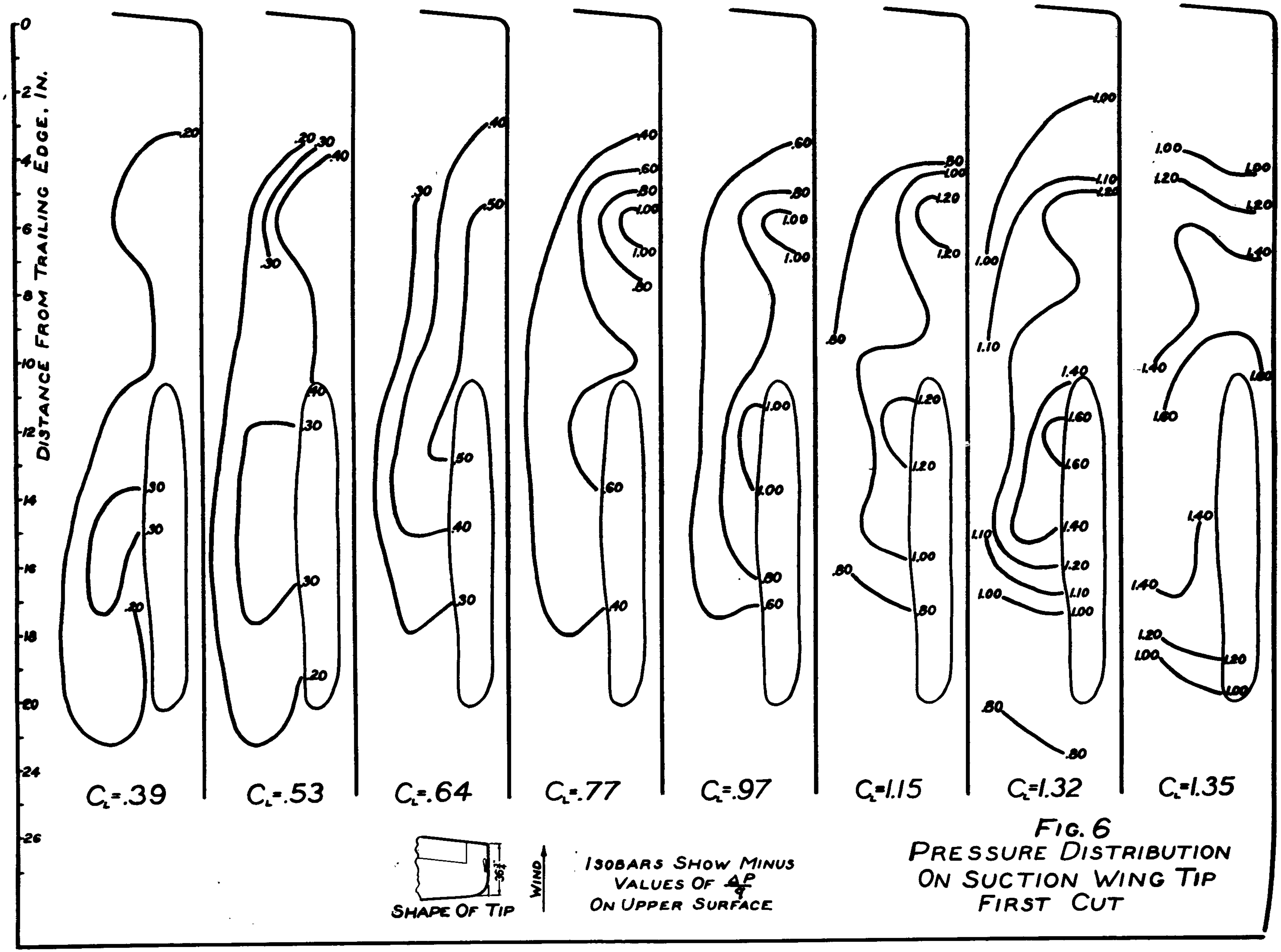


Fig. 6
Pressure Distribution On Suction Wing Tip
First Cut

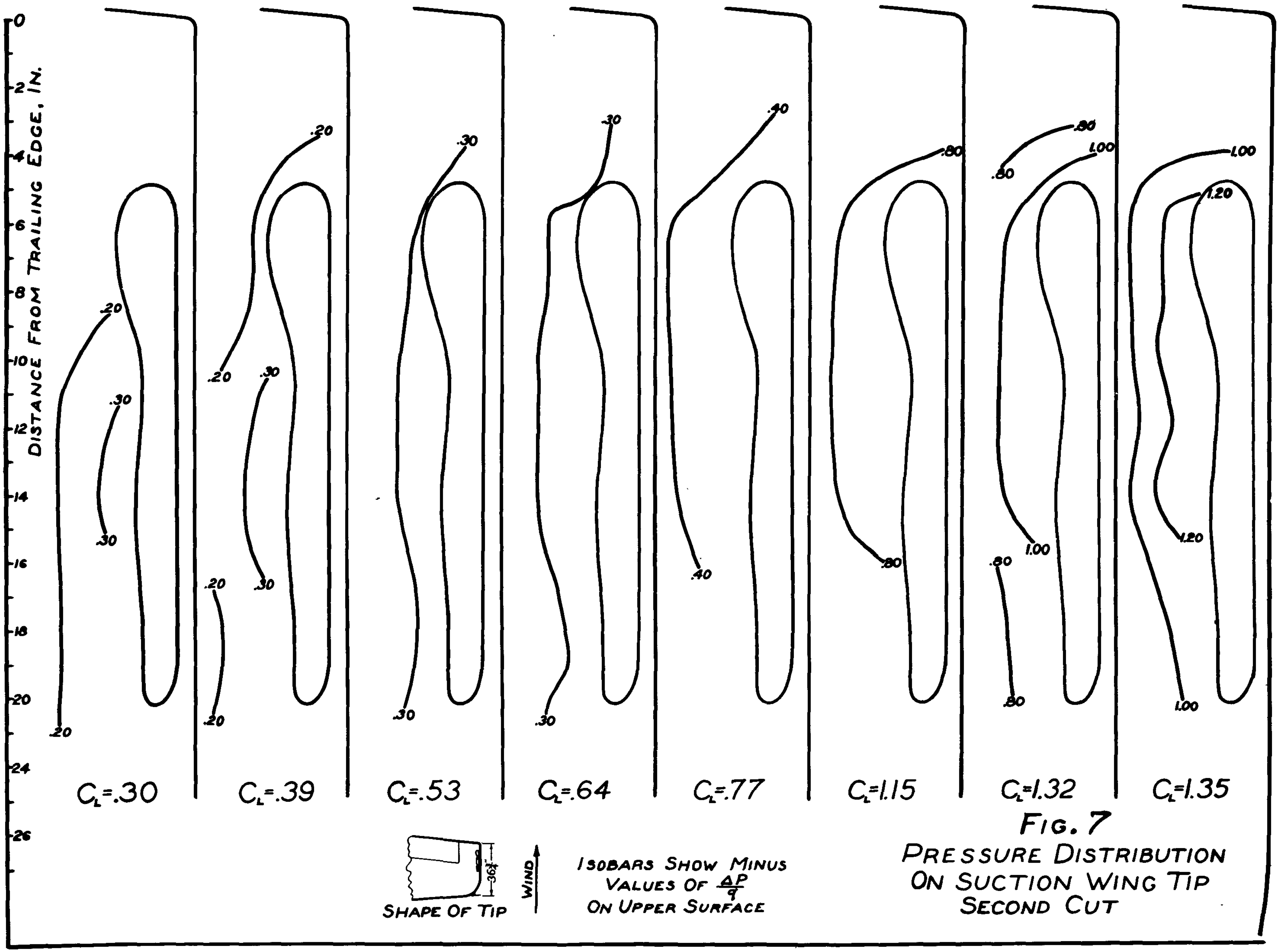


FIG. 7
PRESSURE DISTRIBUTION ON SUCTION WING TIP
SECOND CUT

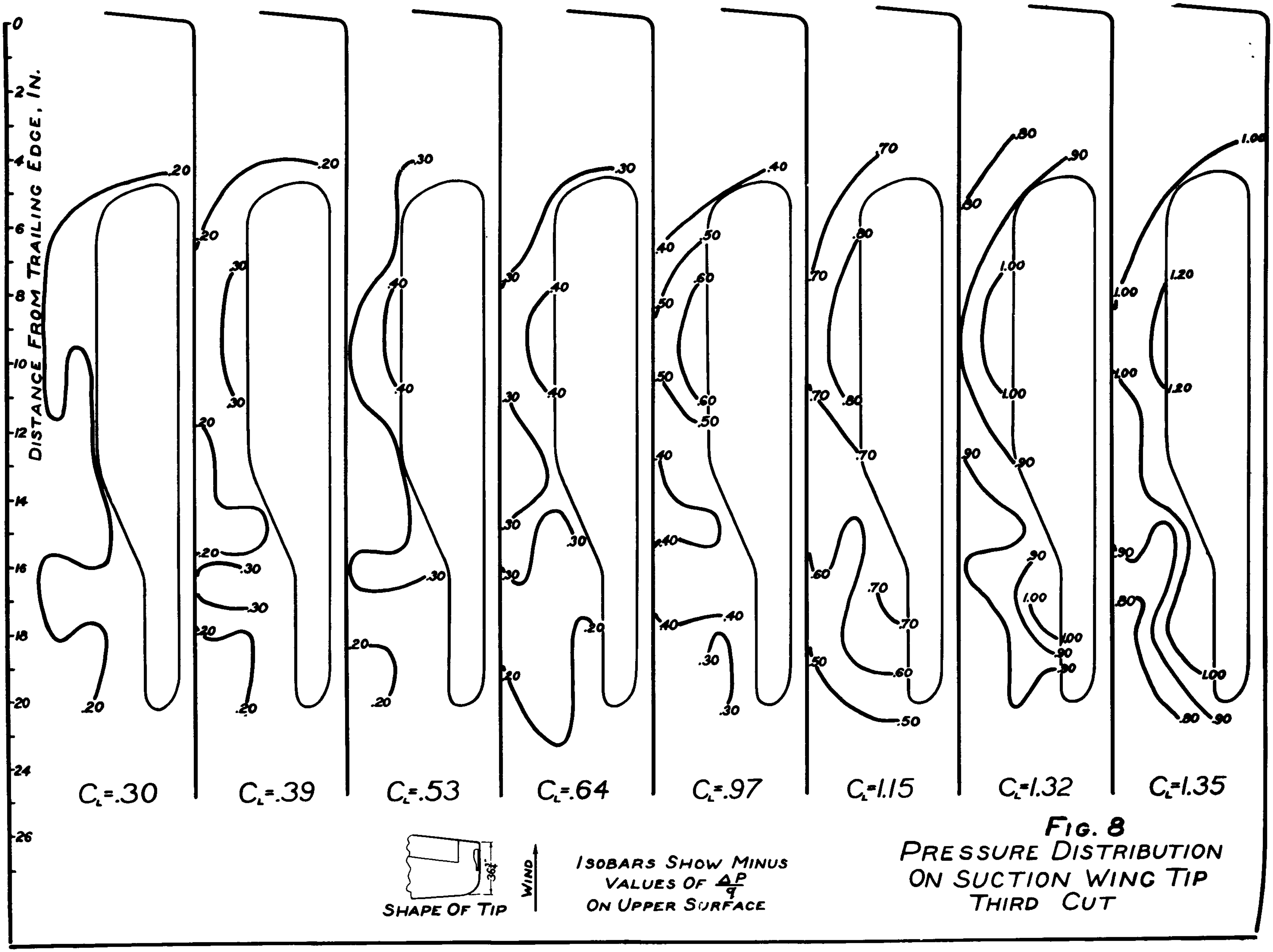
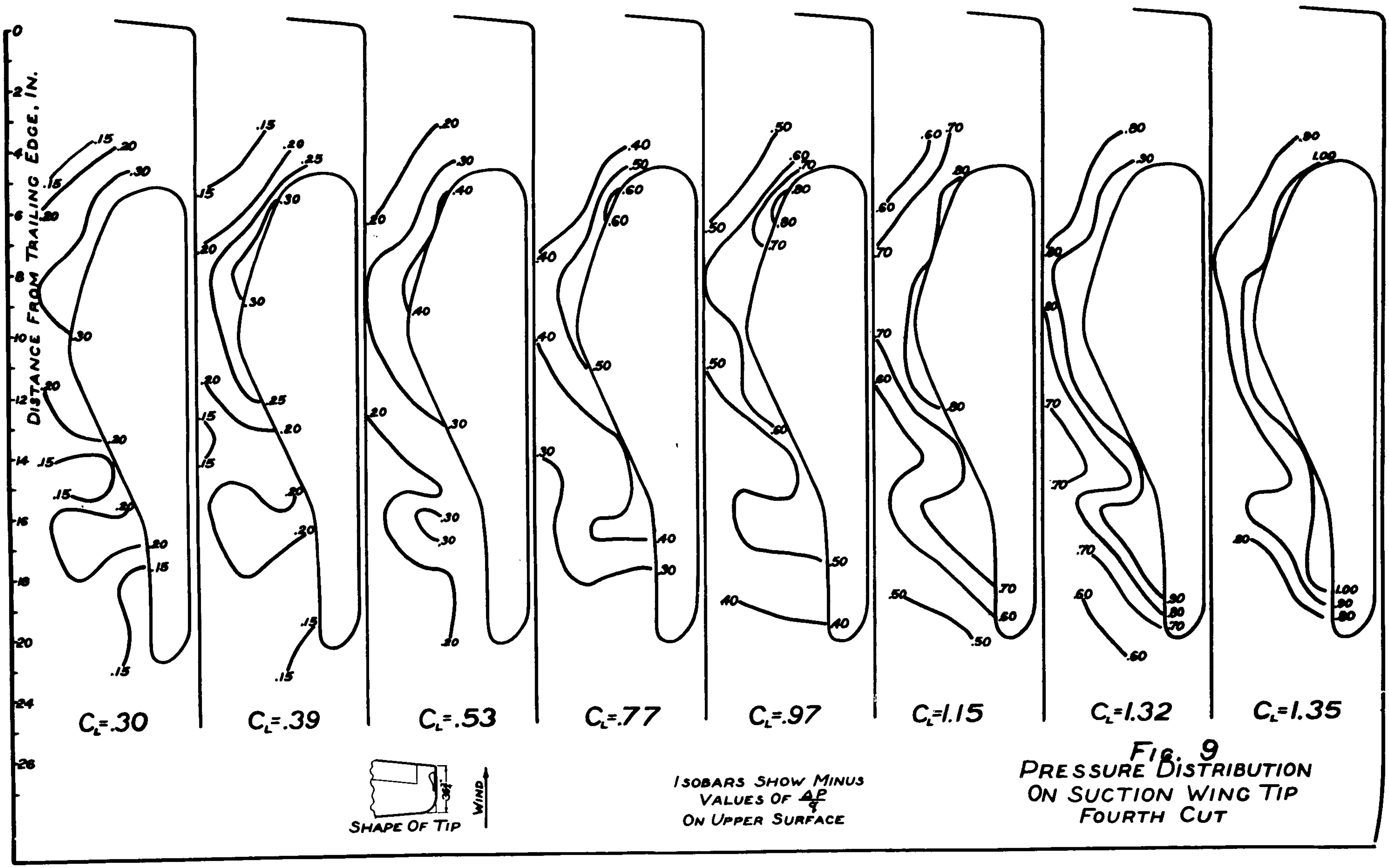


Fig. 8
Pressure Distribution On Suction Wing Tip Third Cut



Isobars Show Minus Values of $\frac{\Delta P}{q}$ On Upper Surface

Fig. 9
Pressure Distribution
On Suction Wing Tip
Fourth Cut

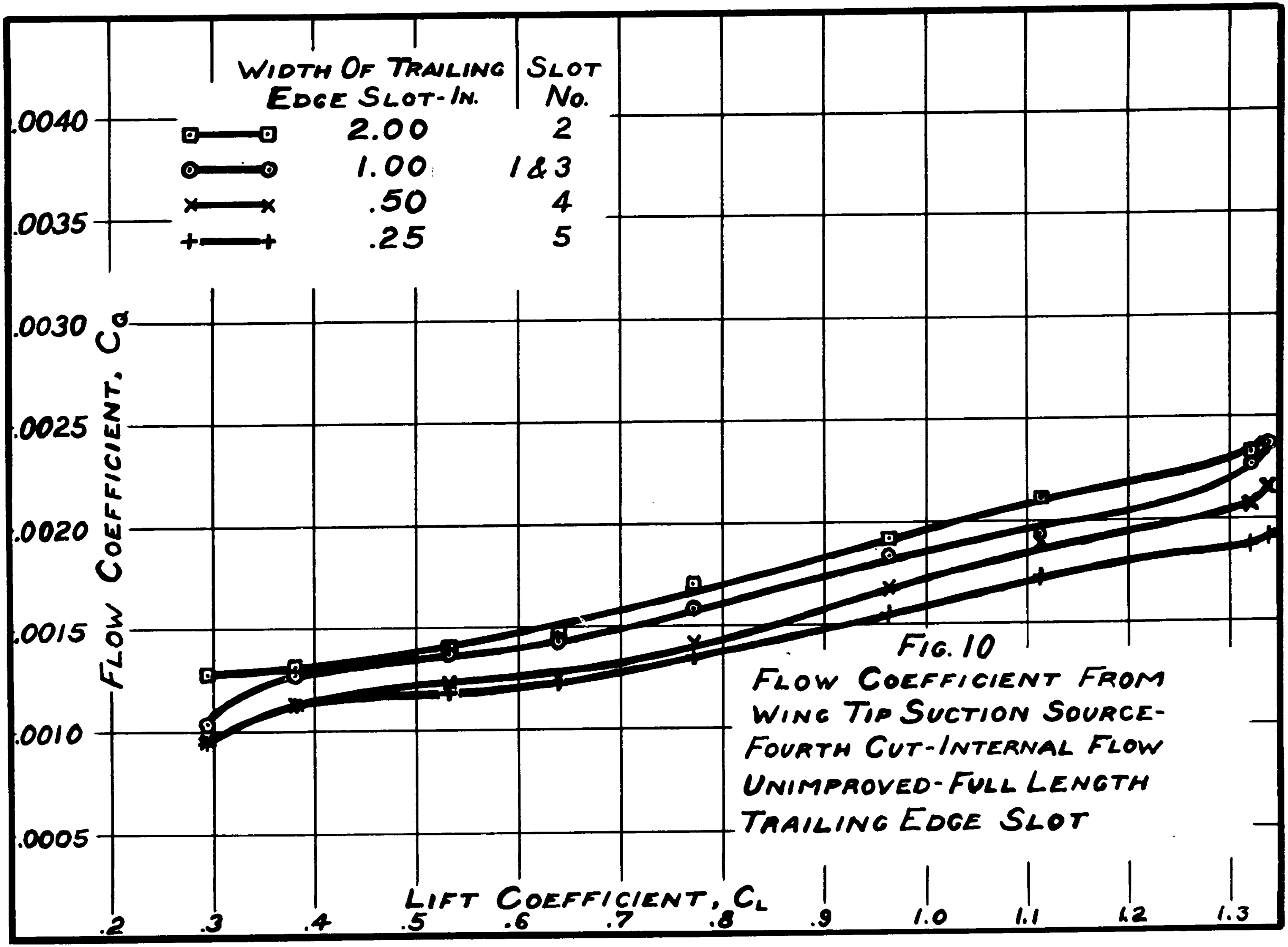


Fig. 10

Flow Coefficient From Wing Tip Suction Source-Fourth Cut-Internal Flow Unimproved-Full Length Trailing Edge Slot

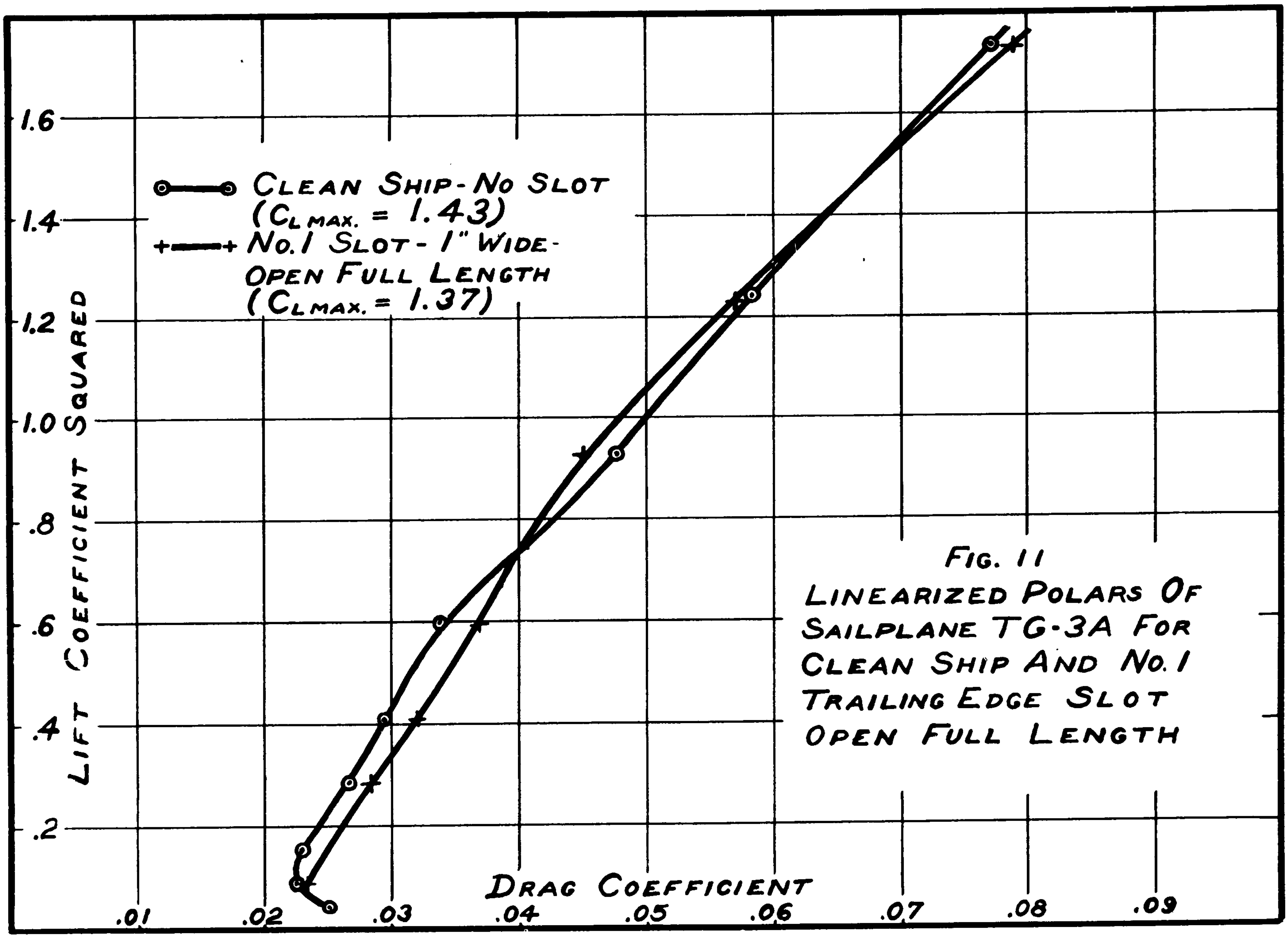


Fig. 11
Linearized Polars of Sailplane TG-3A for Clean Ship and No. 1 Trailing Edge Slot Open Full Length

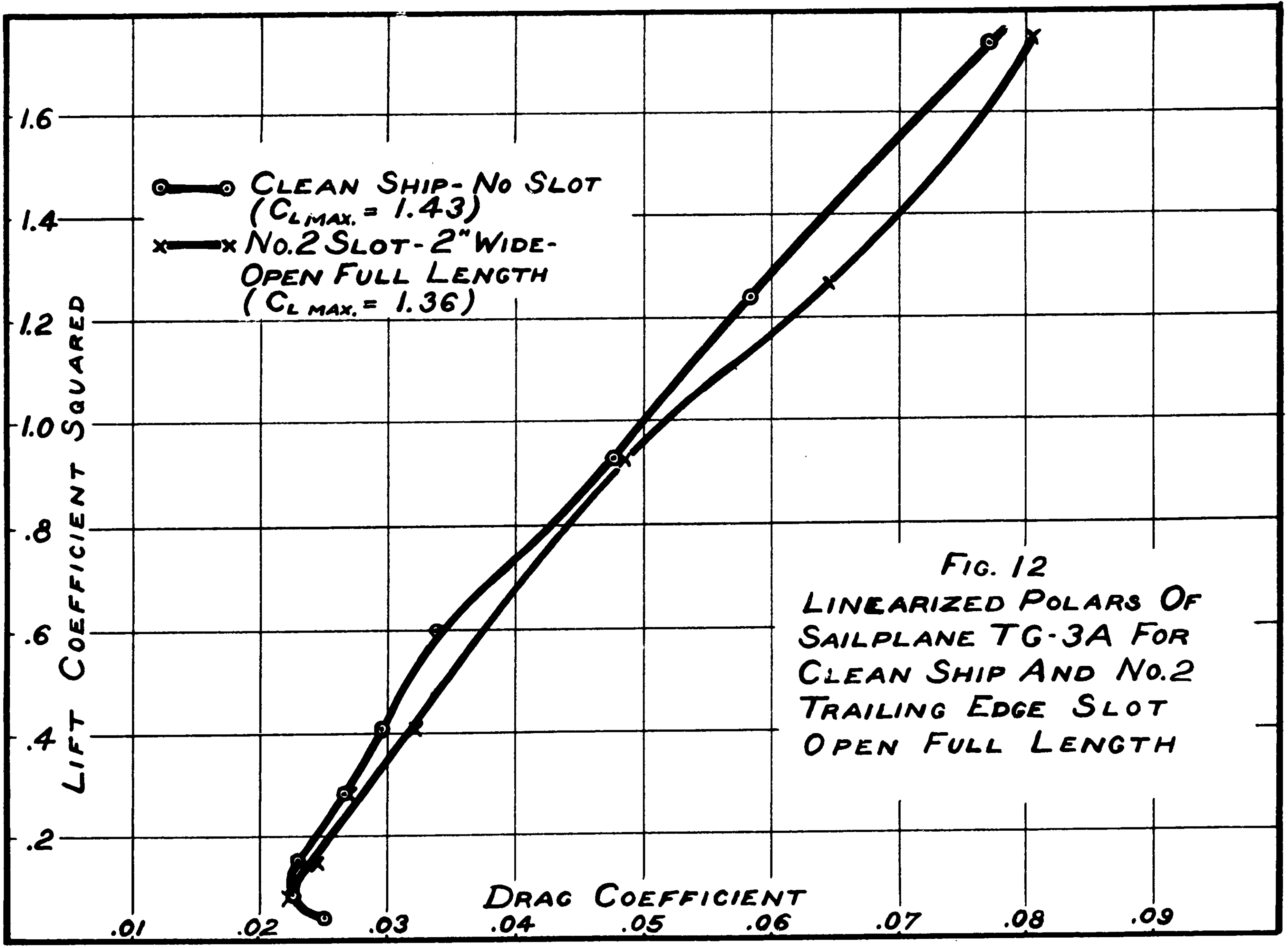


Fig. 12
Linearized Polars Of Sailplane TG-3A For Clean Ship And No. 2 Trailing Edge Slot Open Full Length

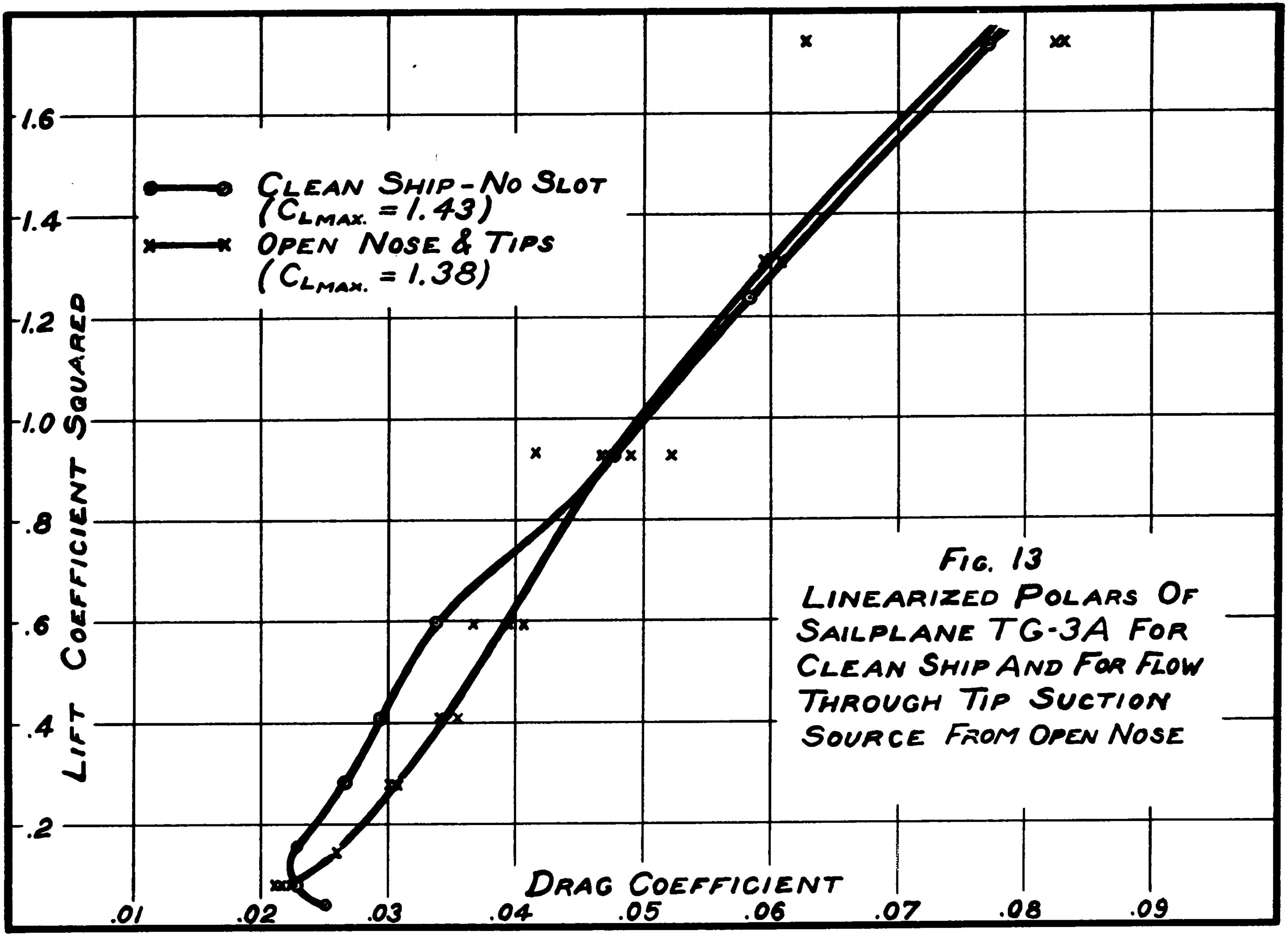


Fig. 13
Linearized Polars Of Sailplane TG-3A For Clean Ship And For Flow Through Tip Suction Source From Open Nose

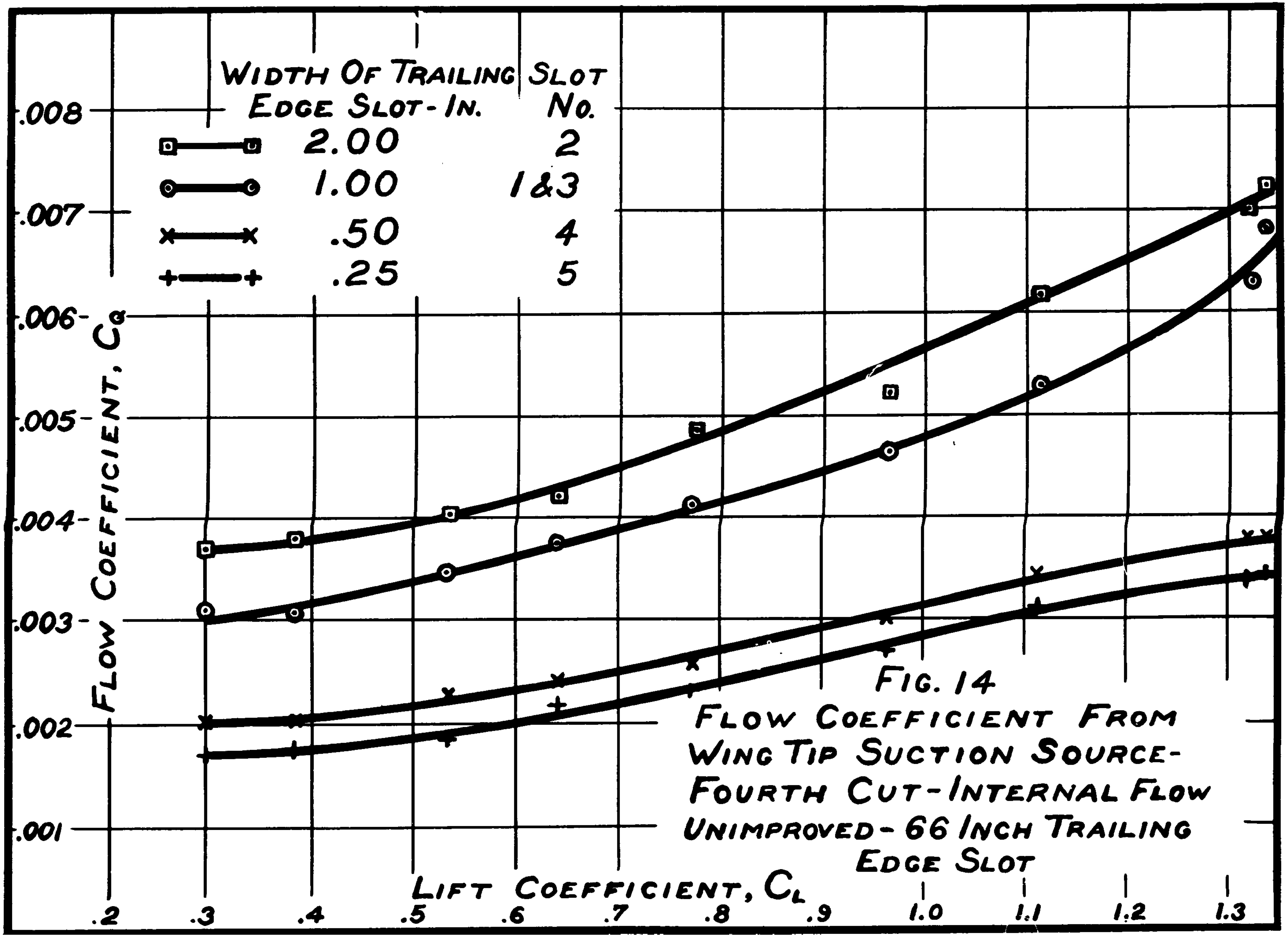


Fig. 14
Flow Coefficient From Wing Tip Suction Source- Fourth Cut - Internal Flow Unimproved - 66 Inch Trailing Edge Slot

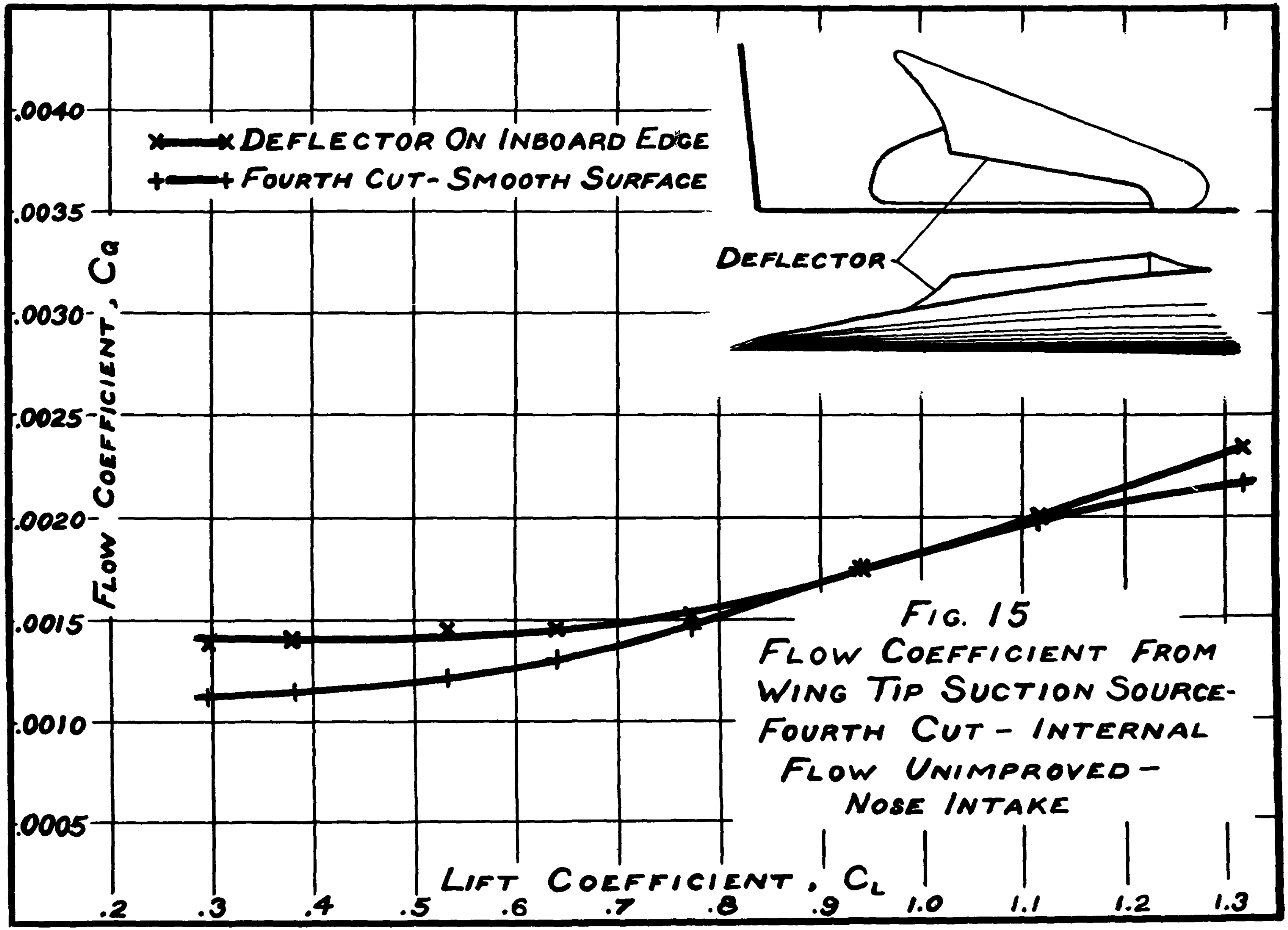


Fig. 15
Flow Coefficient From Wing Tip Suction Source-Fourth Cut - Internal Flow Unimproved - Nose Intake